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CONTENTS

ABSTRACT

Prospective range restoration areas must be judged capable of satisfactory response before restoration is attempted. Both underestimation and overestimation of site potential for such areas have created serious problems for land managers in the juniper-pinyon and sagebrush-grass types.

Reported here are the results of a 5-year study to develop an objective and more reliable system for evaluating site potential.

Productivity of big sagebrush, black sagebrush, and a grass mixture was correlated at 21 representative sites with edaphic, topographic, and climate conditions that significantly affect production. The analysis provided mathematical models from which charts for each plant species group have been developed. A proposed treatment site can be classified broadly for productivity potential. The potential is charted for a range of values of the measurable variables (soil properties, precipitation, percent slope, etc.) that were found to be most strongly associated with production.

INTRODUCTION

Most of the winter big game ranges and a large portion of the winter livestock ranges of Utah are in the juniper-pinyon and sagebrush-grass types. Although approximately 40 percent of Utah, or 20 million acres, is occupied by these two types (Vallentine 1961; Isaacson[1]), more than three-fourths of this acreage is severely depleted of the grasses, forbs, and shrubs necessary to big game survival. The condition of these lands greatly reduces their value to livestock, and water and soil losses are high (Plummer and others 1968) (fig. 1). The importance of these two range types can hardly be overemphasized because they are needed to provide the winter forage base for deer and elk and grazing area for livestock in the spring and fall.

In an effort to improve depleted winter ranges in Utah, more than 200,000 acres in the juniper-pinyon type have been chained and seeded to mixtures of grasses, forbs, and shrubs (fig. 2). Although seeding has been successful on most of this land, stand establishment on some projects has been mediocre or poor. This study was undertaken to improve our ability to evaluate productivity potential of a prospective restoration site. In the past, such evaluation has occasionally been based on soil surveys, but for the most part it has been subjective, based on the personal experience of the individual land manager. The rising cost of improvement projects and the extensive acreage yet unimproved emphasizes the need for reliable criteria for site productivity potential to guide restoration projects.

Little information is available on the productivity potential of the juniper-pinyon and sagebrush-grass communities. Site index research on coniferous and deciduous forests has little application to artificial restoration in juniper-pinyon and sagebrush-grass communities.

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[1]H. E. Isaacson. Ecological provinces within the pinyon-juniper type of the Great Basin and Colorado Plateau. Unpubl. M.S. thesis, Utah State Univ., Logan, 44 p., 1967.

Figure 1.--Juniper-pinyon site where understory has been severely depleted.

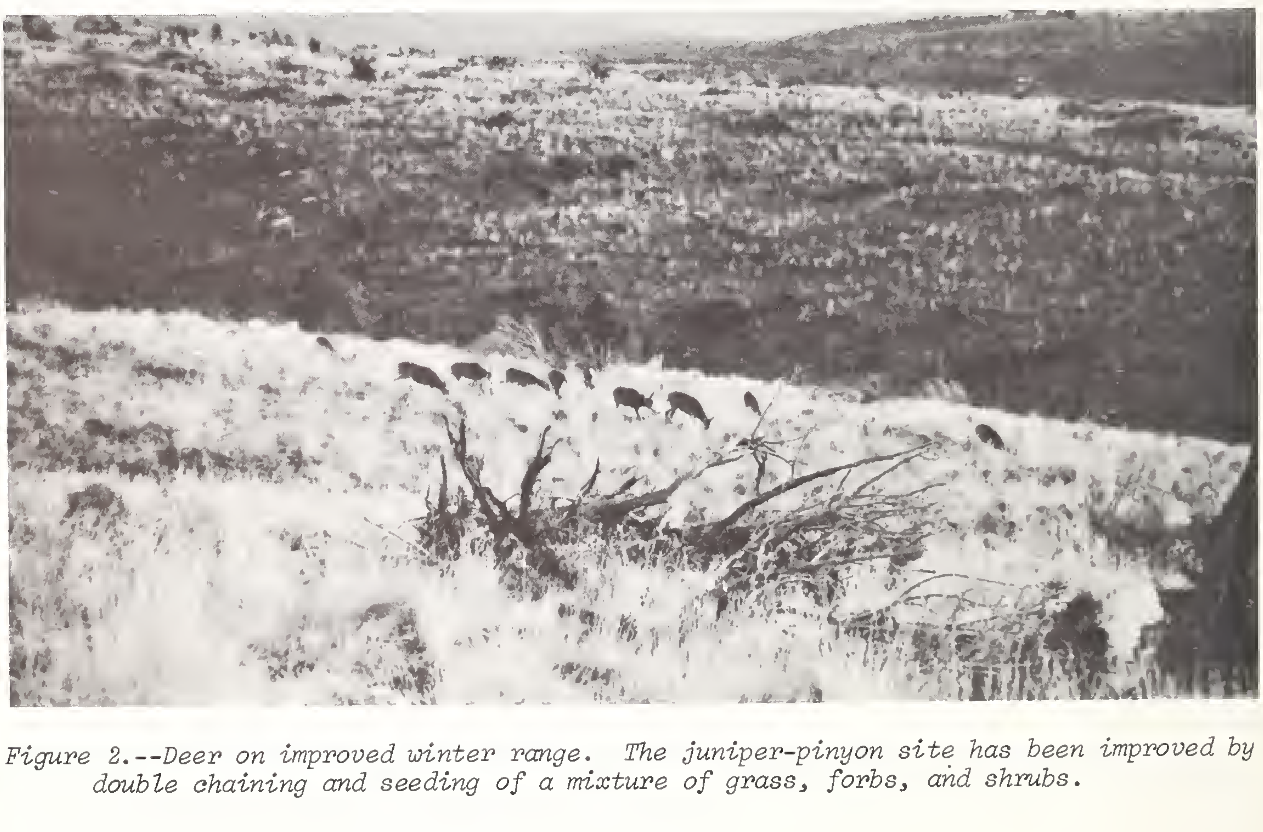

Figure 2.--Deer on improved winter range. The juniper-pinyon site has been improved by double chaining and seeding of a mixture of grass, forbs, and shrubs.

Work closely related to site index research, however, has been done by Gates and others (1956) and by Fosberg and Hironaka (1964), who report the significant effect of selected soil properties on the distribution of plants in Utah and Idaho. Yield and composition tables have been compiled for most range sites in Utah, and these have been correlated with precipitation and soil (Mason 1971). Medin (1960), working with mountain mahogany (*Cercocarpus montanus*), also found that soil and topographic characteristics affect annual production. Davis[2] reported from Nevada that some soil properties, along with precipitation, are useful in estimating production on a salt desert range.

Research has shown how variations in precipitation affect herbage production of certain grass and shrub species in the sagebrush-grass and juniper-pinyon communities (Cooper and Hyder 1958; Passey and others 1964; Blaisdell 1958; and Clary 1971). Hutchings and Stewart (1953) discovered that precipitation is the most important influence on production of a number of shrubs and grasses in the salt desert shrub type. Currie and Peterson (1966), working in Colorado, found that growing-season precipitation could be used to predict yields of established standard crested wheatgrass (*Agropyron desertorum*).

This study seeks to identify edaphic, topographic, and precipitation variables that significantly influence annual production on winter game range in Utah, and to find ways to use these variables to predict productivity potential of a given site. The study included big sagebrush, black sagebrush, a mixture of perennial grasses, winter rye, and German iris on 21 sites. The winter range studied is used from late fall through early spring. Regression analysis of the resulting data resulted in the development of three prediction models and finally, in productivity-potential charts for easy application by users.

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[2]J. Barry Davis. Estimating plant production from soil and floristic correlates in Hot Creek Valley, Nevada. Unpubl. M.S. thesis, Univ. Nevada, Reno, Renewable Natural Resources, 58 p., 1971.

STUDY AREA

Twenty-one study sites, which we believe to be representative of Utah's principal big game winter ranges, were selected in central Utah. Thirteen are located within juniper-pinyon communities, two on ecotones between the mountain brush and juniper-pinyon types, three in sagebrush-grass communities (fig. 3), two on abandoned dry farms formerly occupied by juniper and sagebrush (fig. 4), and one within a shadscale-sagebrush community. Slopes vary from 0 to 41 percent and exposures are primarily west and south. Soil pH ranges from 7 to 8.9. A calcium carbonate layer is present on most sites, but only on the shadscale-sagebrush area is there a cemented hardpan. Annual precipitation varies from 5 to 25 inches.

Soils of the 21 sites are derived from eight geologic formations. From oldest to youngest they are (1) Lower Oquirrh formation--mostly quartzite with some shale, (2) Upper Oquirrh formation--mostly limestone with some shale, (3) Arapien formation-calcareous shale with sandstone and shale, (4) North Horn formation--sandstone and shale, (5) Flagstaff formation--limestone with some calcareous shale, (6) Colton formation--hematitic, calcareous shale with some sandstone and conglomerate, (7) Green River formation--limestone with some calcareous shale, and (8) extrusive volcanics--mostly porphyritic Andesite (personal communication, Frederic C. Lohrengel II, 1972).

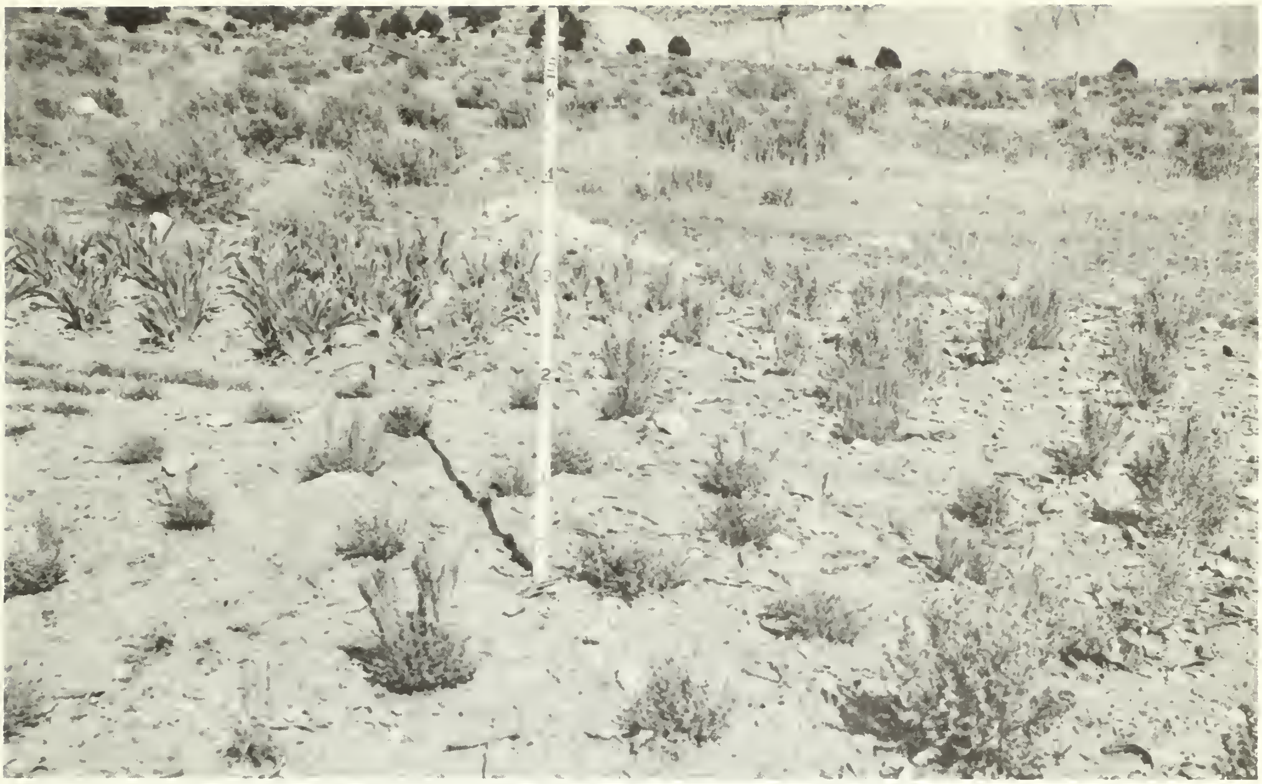


Figure 3.--Study site within a sagebrush-grass community 2 years after plot establishment. The production potential for this area was found to be below average for big sagebrush, black sagebrush, and the grass mixture.

Figure 4.--Study site on abandoned dry farm 2 years after establishment. The potential production of this site was found to be above average for black sagebrush and average for big sagebrush and the grass mixture.

METHODS

Species and Plot Design

A number of plant species having different growth requirements were selected to measure productivity. Big sagebrush (*Artemisia tridentata*) and black sagebrush (*A. nova*) are fast-growing, palatable shrubs, well-adapted to winter big game ranges in Utah. Fairway crested wheatgrass (*Agropyron cristatum*), intermediate wheatgrass (*A. intermedium*), Russian wildrye (*Elymus junceus*), and southern smooth brome (*Bromus inermis*) have a wide range of adaptability and have been successful on many seeding projects. These grasses were planted as a mixture. Because the shrub and grass species selected may require different conditions for maximum production, it was not expected that an optimum site for one species would necessarily be an optimum site for all.

Two other species were planted to determine if their production on a given site could be used as an index to potential productivity for the above-named sagebrush and grass species. They were annual winter rye (*Secale cereale*) and German iris (*Iris germanica*). Both have a wide range of adaptability.

At each site, 2-year-old seedlings of big sagebrush, black sagebrush, and iris rhizomes were planted in April 1964. Transplants of each species were obtained from the same populations to reduce ecotypic variations within a species. The perennial grass mixture and winter rye were sown in November 1964. Winter rye was also sown in the fall of 1965 and 1966. All plantings and seedings were arranged in twice-replicated, randomized blocks (fig. 4). Each block of big sagebrush, black sagebrush, and iris contained five 15-foot rows with six plants per row. The rows were on 30-inch centers. Blocks for the grass mixture and winter rye consisted of eleven 6½-foot rows each with 15-inch centers. The grass mixture (comprised of equal weights of each species) and winter rye were sown at the rate of 10 and 40 pounds per acre respectively.

Border rows in each species were used as isolation strips between species plots. Responses from these plants were not included in the data analysis. Plants other than the test species were periodically weeded out to eliminate outside competition as a complicating factor. Livestock was excluded from each study site.

Measurements

When plots were established, percent slope and exposure azimuth were measured at each site.

Soil examinations at each site were made in accordance with standard Soil Conservation Service soil survey methods (USDA Soil Survey Staff 1951). Soil profile pits were dug and total depth in inches of each recognizable horizon was measured. For each horizon, mottling, color, texture, structure, consistency, and percent coarse fragments (greater than 3/4-inch diameter) hereinafter referred to as percent rock, by volume were recorded. Soil samples for each horizon were collected and analyses were made for percent soil organic matter, pH, percent calcium carbonate, percent nitrogen, available phosphorus pentoxide (P_2O_5) in pounds per acre, available potassium in parts per million, cation exchange capacity, expressed on a percent-by-weight basis for the less-than-2-mm fraction, and moisture-holding capacity at 1/3 and 15 atmospheres.

Precipitation was measured at or near each site for the duration of the study with standard 8-inch precipitation gages.

Herbage production was the variable measured as a predictor. Initially, total herbage production, height, and crown spread measurements were considered to be the variables most likely to have predictive value. Preliminary analysis showed, however, that production was a much better expression of plant response than either height or crown spread, and consequently, these two variables were eliminated. The weight estimate method described by Pechanec and Pickford (1937) was used to determine field green-weight production. Green weights were later converted to air-dry weights for analysis.

Herbage production of winter rye was measured annually from 1965 to 1967. Production measurements on the other species were not made until the plants were near maturity in 1967. Production was measured again in 1968 and 1970. In the latter part of June 1968, one of the most severe June frosts on record occurred, preventing normal development of seed heads in the big and black sagebrush. Grass forage, which was almost completely frozen, had little regrowth, and there was no seed head development after the frost. The reduced and erratic production measurements for 1968 were not included in the data analysis.

Data Analysis

The analysis of the data gathered in the study was aimed at isolating the environmental variables that could best serve as production predictors. Plot soil characteristics, slope, exposure, and precipitation, in all combinations, were screened as independent variables in linear additive regression models, for strength of relation to corresponding 1967 and 1970 dry-weight production estimates. Those variables contributing most strongly to R^2 (that is, explaining the greatest amount of variance in production) and having direction of effect in accord with biological expectation were identified. For these variables, a more sensitive interaction model was subsequently developed as explained in the Appendix. This process, in its entirety, was applied to the data for big and black sagebrush and the grass mixture.

The three final models formed the basis for the productivity charts presented. Future data accumulated in field use may permit improvement in the predictive accuracy of the interim formulas and charts developed.

Note that neither iris nor rye proved suitable as productivity indicators. Iris had suffered extensive fungal damage and rye production was unaccountably variable.

RESULTS

Perennial Grass Mixture

For the grass mixture, the variables most strongly associated with production were those related to available soil moisture during the growing season. They included annual water-year precipitation, May precipitation, percent rock in the subsoil, and percent slope. The model that included these variables produced a coefficient of determination (R^2) of 0.76. In general, the production responses were in accord with biological expectations.

Expectations.--In semiarid areas, precipitation limits production. With increases in either May or annual precipitation, the curve of expected production is sigmoid (S-shaped). Because May is generally the period of maximum growth in the areas under consideration, precipitation received during this period can be of critical importance. At the extreme of no precipitation in May and no residual soil moisture from winter or early spring precipitation, there would be little or no production because soil moisture would be below the wilting point for grasses. As precipitation increased to the point where soil moisture was available, production could be expected to increase until added increments of precipitation could not be effectively utilized by the plants, and the production curve would tend to level off. The same expectation would presumably hold between extremes of annual precipitation; high annual precipitation does not occur in this area, however.

Grass production was expected to diminish sigmoidally with increased rockiness in the subsoil, which reduces the water-holding capacity of the profile. The fact that the grasses have shallow fibrous root systems and were planted in soils with very shallow A horizons would tend to accentuate this effect.

The relation of the amount of moisture entering the soil to the amount of precipitation depends, at least in part, on the slope of the area. At zero slope, the infiltration of moisture, the resulting soil moisture level, and grass production are expected to be near a maximum. With increased slope, overland flow and erosion increase and infiltration decreases, reducing soil moisture storage and grass production. The expectation was for a sigmoidal decrease between extremes of slope.

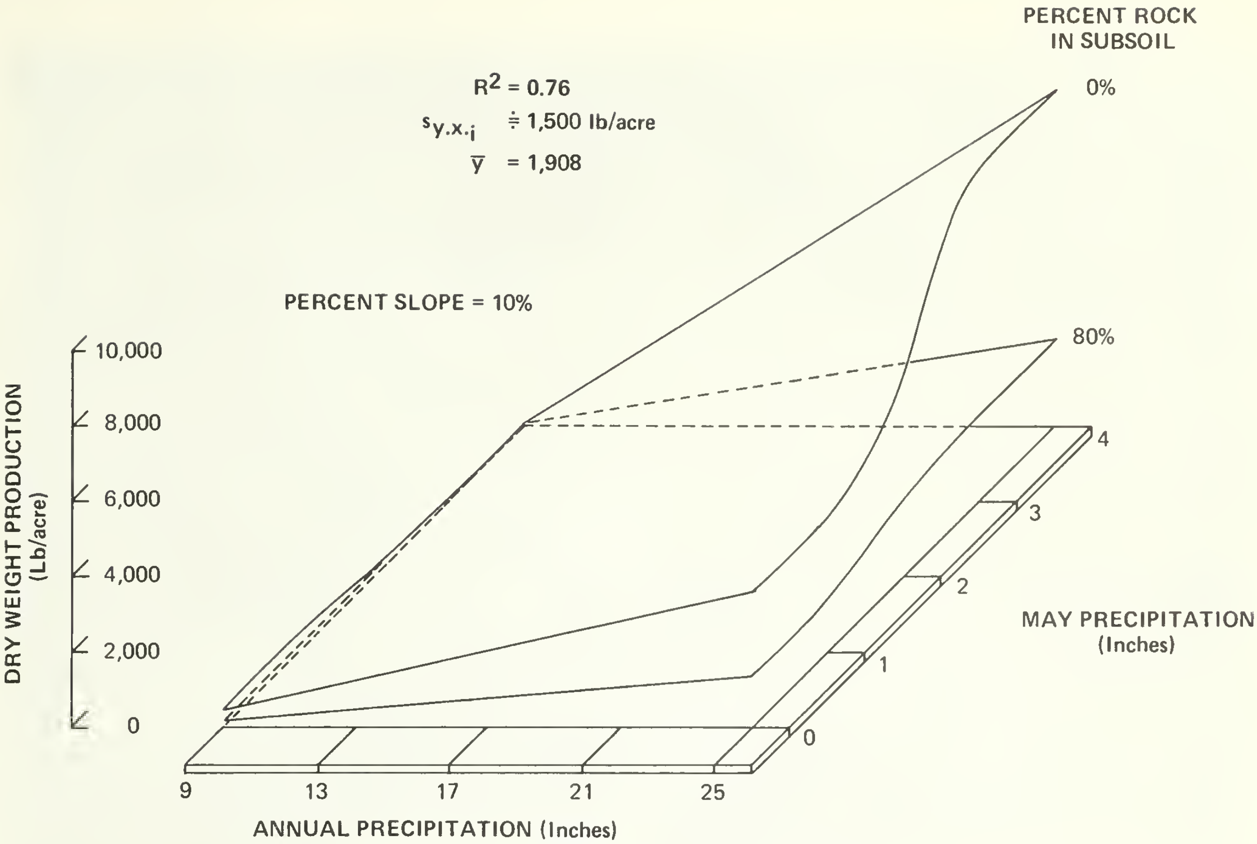


Figure 5.--Graphic illustration of the effect of four variables (annual precipitation, May precipitation, and percent rock in the subsoil at three levels all at an average slope of 10 percent) on the production of a grass mixture.

Results.--During the course of the study, May precipitation ranged from 0.1 to 3.3 inches; as May is the period of greatest growth of all species in the grass mixture, it was not surprising that May precipitation exerted a full, strong sigmoidal effect on production, the greatest increase occurring between 1 and 3 inches of precipitation.

For annual precipitation, percent rock, and percent slope, the expected production response was fundamentally realized, but only linear portions of the expected sigmoidal effects could be identified in the analysis. Perhaps this incomplete response was due to the limited range in annual precipitation (5 to 25 inches) and percent slope (0 to 21 percent, only one site exceeding 21 percent) on the study areas. Percent rock, however, ranged broadly (0 - 80 percent), and the expected negative relation to production was evident.

It was possible to identify the interaction between precipitation variables and percent rock, and this was incorporated in the final prediction model. After interaction was fitted, slope was fitted as an additive effect. The magnitude of effects in the three-way interaction can be seen in figure 5. Note that the change between surfaces at 0 and 80 percent rock is a linear function of percent rock. The linear effect of slope (not shown) is small.

Big Sagebrush

The components of the production model for big sagebrush were found to be annual precipitation and depth of the soil horizons A through C^1 (R^2 = 0.56). May precipitation had no discernible effect on production. Apparently big sagebrush, a relatively

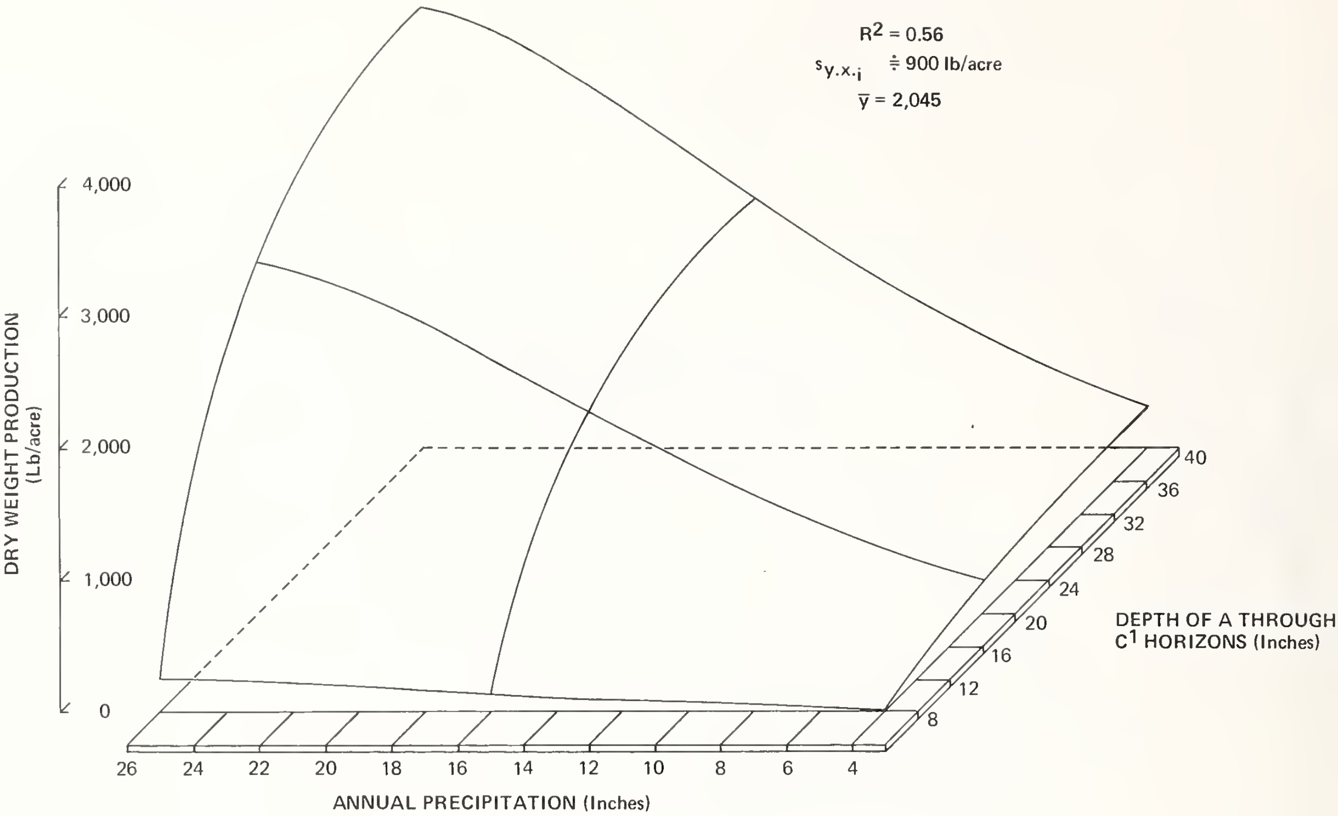


Figure 6.--Graphic illustration of the effect of annual precipitation and depth of horizons A through C1 on the production of big sagebrush.

deep-rooted species, is not very sensitive to moisture fluctuations in the surface horizons that result from either a wet or dry May. Most of the annual growth of this species is probably dependent on deep soil water reserves.

The expected sigmoidal effect of annual precipitation on production was not evident over the relatively limited range of annual precipitation (5 to 25 inches). The data revealed a production trend that was basically linear.

The appearance of depth of horizons A through C^1 as a model component again seems reasonable--this depth would be a critical factor in root development and available moisture-holding capacity for a deep-rooted species. With no soil depth, production should be zero, but it could be expected to increase with greater depth of horizons A through C^1 up to a point of diminishing return, that is, one at which added depth would not be wetted even in the highest precipitation areas included in the study. Extremes of depth of horizons A through C^1 occurred on the study sites, and the expected sigmoidal effect on production was readily apparent from the data.

Production tended to level off when depth of the C^1 horizon was more than 34 inches. The soil types on the sites and the amount of precipitation in normal years suggest that any water percolating deeper than 34 inches is probably not available for long periods. Consequently, a C^1 horizon deeper than 34 inches without moisture would not be expected to greatly increase production. The magnitude of the final interacting effect of two variables on production for big sagebrush is shown in figure 6.

Figure 7.--Three-year-old plants of black sagebrush and big sagebrush, showing the more fibrous root system of black sage and the deep taproot of big sage.

Black Sagebrush

The model for this species included annual precipitation, percent rock in the subsoil, and depth to the point of rapid increase in concentration of calcium carbonate (R^2 = 0.65).

This species typically has a more shallow fibrous root system than big sagebrush (fig. 7). Consequently, the species is more responsive than big sagebrush to variables associated with moisture near the soil surface. Therefore, it was thought that May precipitation should show as a significant variable in production of black sagebrush as it did for the grasses. As for big sagebrush, however, only a linear annual precipitation effect could be identified in the data. Perhaps this incomplete response could be attributed to the limited range in precipitation.

Black sagebrush has been observed to grow most often in rocky to semirocky, well-drained soils, leading to the assumption that small amounts of rock in the subsoil may not be detrimental to production. The expected sigmoidal effect of percent rock on production was evident, however. No doubt as rock percent reaches a given level, moisture storage capacity does become limiting and results in reduced herbage production. Although there was relatively little production loss between 0 and 20 percent rock, production declined to near 0 when rock content neared 80 percent.

Forage production is usually low on soils with shallow calcium carbonate layers. Under certain conditions, depth to the carbonate layer is a fairly reliable index to

the average annual precipitation. Such conditions as position of the contrasting soil layers and presence of and rates of deposition and erosion complicate evaluation of the influence of the calcium carbonate layer in relation to the other variables. As this layer appears at greater depths, the available moisture, aeration, and potential rooting area may also be greater, depending on the thickness of the layer and the amount of cementing which has taken place. The broad range of this variable in the data (0 to 50+ inches) enhanced the strong sigmoidal effect that was evident. Virtually all the change attributable to depth of the calcium carbonate layer occurred in the range of 0 to 12 inches. Black sage production was finally expressed as a function of the three-way interaction of these variables as shown in figure 8.

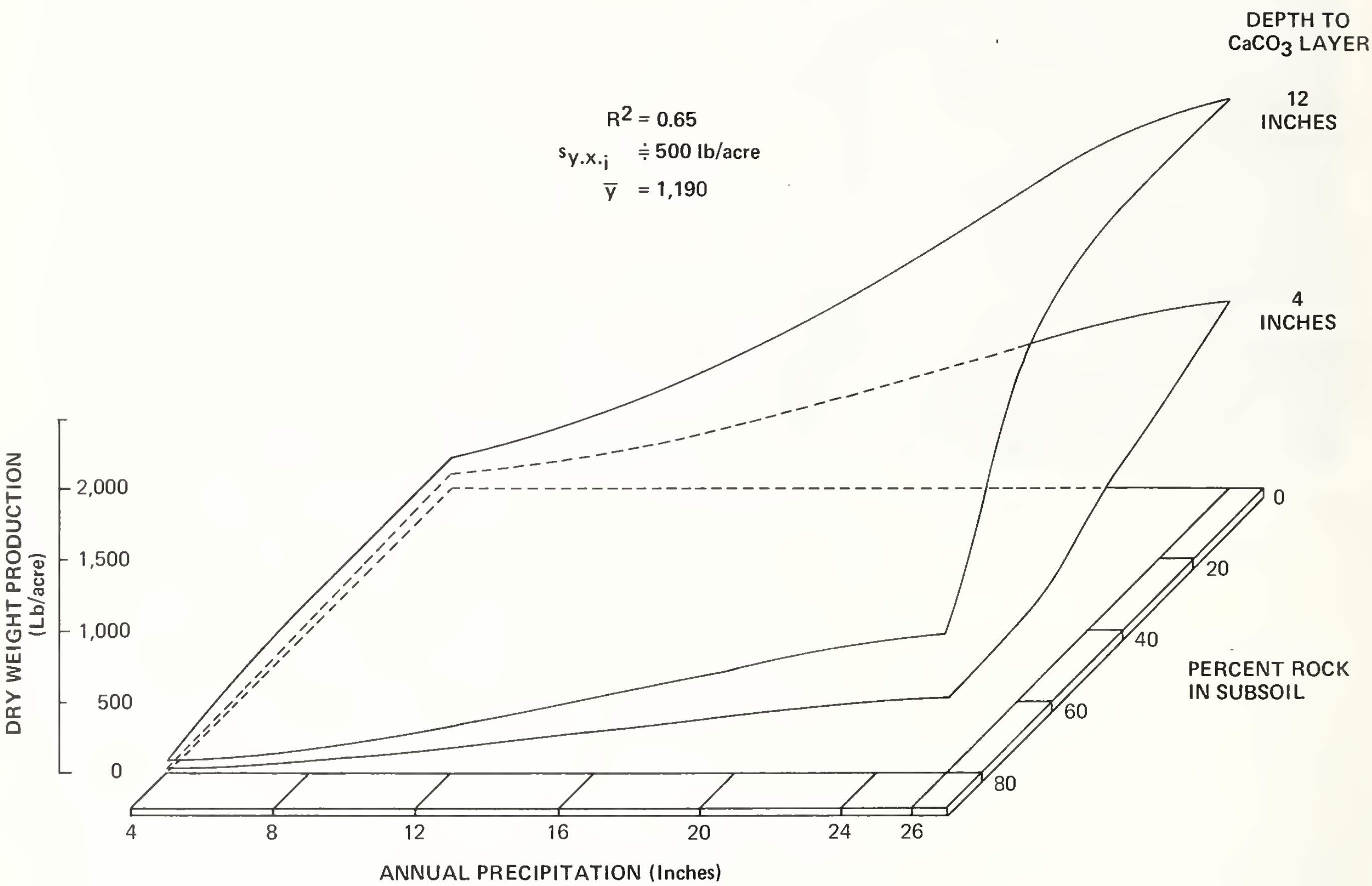


Figure 8.--Graphic illustration of the effect annual precipitation, percent rock in the subsoil, and three depths to a calcium carbonate layer have on the production of black sagebrush.

PRODUCTIVITY-POTENTIAL CHARTS

The derivation of estimating equations for each plant species group from the initial production model is described in the Appendix. The equations were used as the basis for computerized production estimates for pertinent levels of the variables in each model. The estimates for each species group were then divided into five productivity-potential groups: (1) low; (2) below average; (3) average; (4) above average; and (5) high. The predicted range in production (pounds per acre) of the five productivity groups under mature, full, pure stand conditions are given in table 1.

Table 1.--*Productivity-potential groups and their predicted range of production under mature, full, pure stand conditions for each species*

Productivity groups	Predicted range of production		
	Grass mixture	Big sagebrush	Black sagebrush
	Air-dry lb/acre		
1. Low	0 - 299	0 - 199	0 - 199
2. Below average	300 - 1,199	200 - 699	200 - 599
3. Average	1,200 - 2,999	700 - 1,499	600 - 1,399
4. Above average	3,000 - 4,499	1,500 - 2,199	1,400 - 1,999
5. High	4,500 -	2,200 -	2,000 -

We do not expect that pure, full stands over an entire area will be achieved or are even desirable for any one species under most range conditions. We judge the use of specific production estimates rather than broad productivity groups to be unwise because of sampling and measurement constraints in the basic data. Actual production will vary from that predicted by reason of factors not accounted for in these models, such as quality and quantity of seed, adaptability of species, methods used in site preparation and seeding, time of seeding, moisture and temperature conditions during establishment period, and season and degree of use.

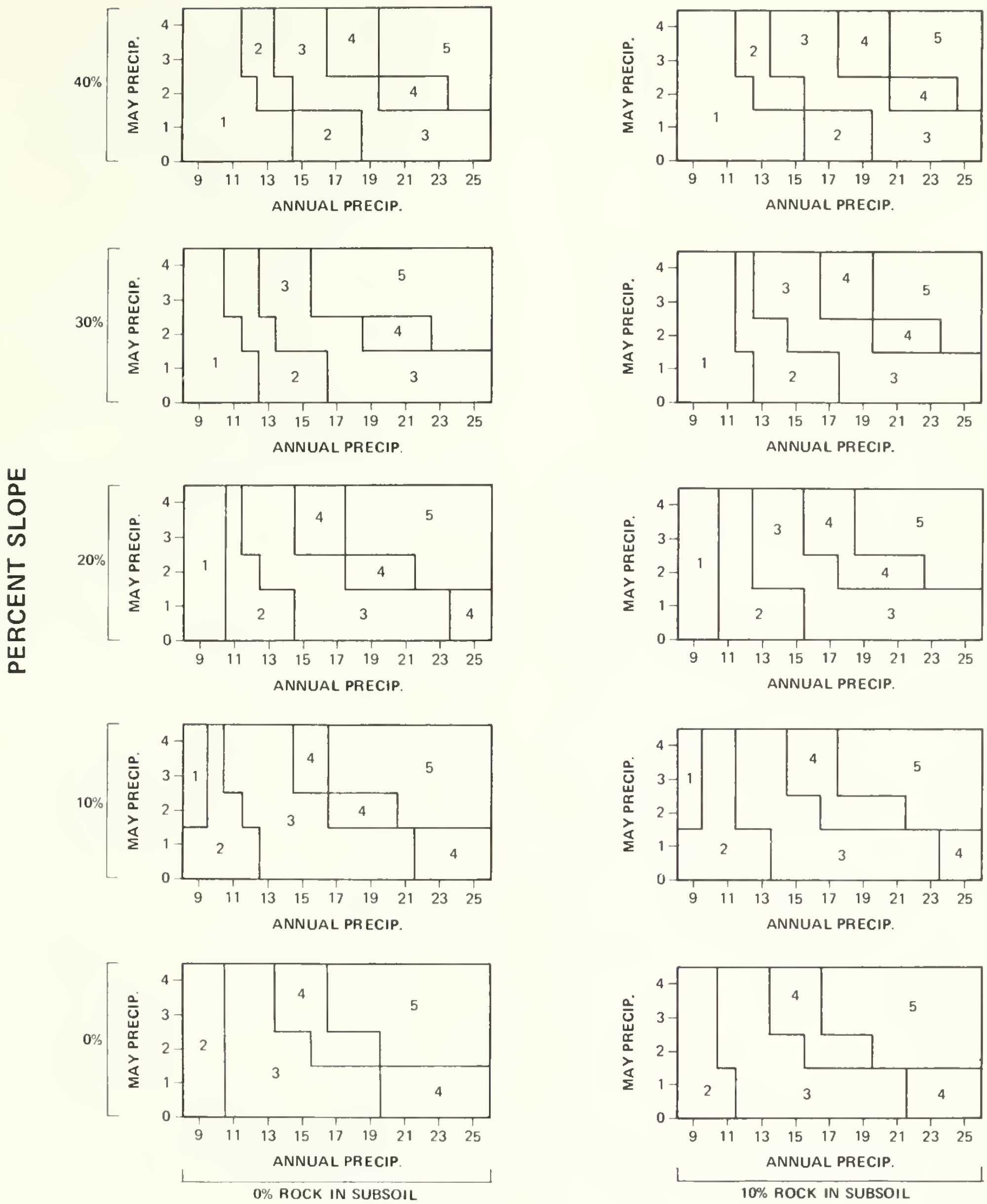
The productivity-potential tables for the three species are given in figures 9, 10, 11, 12, and 13. With these charts, proposed treatment sites may be classified according to productivity group. Where a grass mixture is to be planted, the average water-year precipitation, average May precipitation, percent slope, and percent rock (larger than 3/4 inch) in the subsoil should be determined. For big sagebrush, information is needed on average water-year precipitation and depth of the A through C^1 horizons. Where black sagebrush is to be seeded, knowledge of average water-year precipitation is required along with percent rock (larger than 3/4 inch) in the subsoil, and if applicable, the depth to the point (if present) of rapid increase in concentration of calcium carbonate. Where such a point is not present, a figure of 40 inches may be used. A concentration of calcium carbonate at this depth and deeper has no significant effect on production and is therefore the greatest depth indicated in the charts. When the appropriate information is obtained for a given area, the productivity classification of that area can be readily obtained by applying the data to the appropriate chart in figures 9, 10, 11, 12 and 13 as illustrated in table 2.

The guides outlined herein should be applicable throughout most of the range of juniper-pinyon and sagebrush-grass types.

Table 2.--*Example of data required and charts used to determine productivity-potential classification groups for each species for a specific site*

Species	Variables required	Measurements from site	Productivity classification group for site
Grass mixture	Percent rock in subsoil	20	Group 3 (average) from figure 10
	Percent slope	10	
	Annual water-year precipitation (Oct. 1-Sept. 30)	16.2 in.	
	May precipitation	1.8 in.	
Big sagebrush	Annual water-year precipitation (Oct. 1-Sept. 30)	16.2 in.	Group 4 (above average) from figure 12
	Depth of soil horizons A through C^1	27.0 in.	
Black sagebrush	Percent rock in subsoil	20	Group 4 (above average) from figure 13
	Annual water-year precipitation (Oct. 1-Sept. 30)	16.2 in.	
	Depth to $CaCO_3$ layer	31.0 in.	

GRASS MIXTURES I



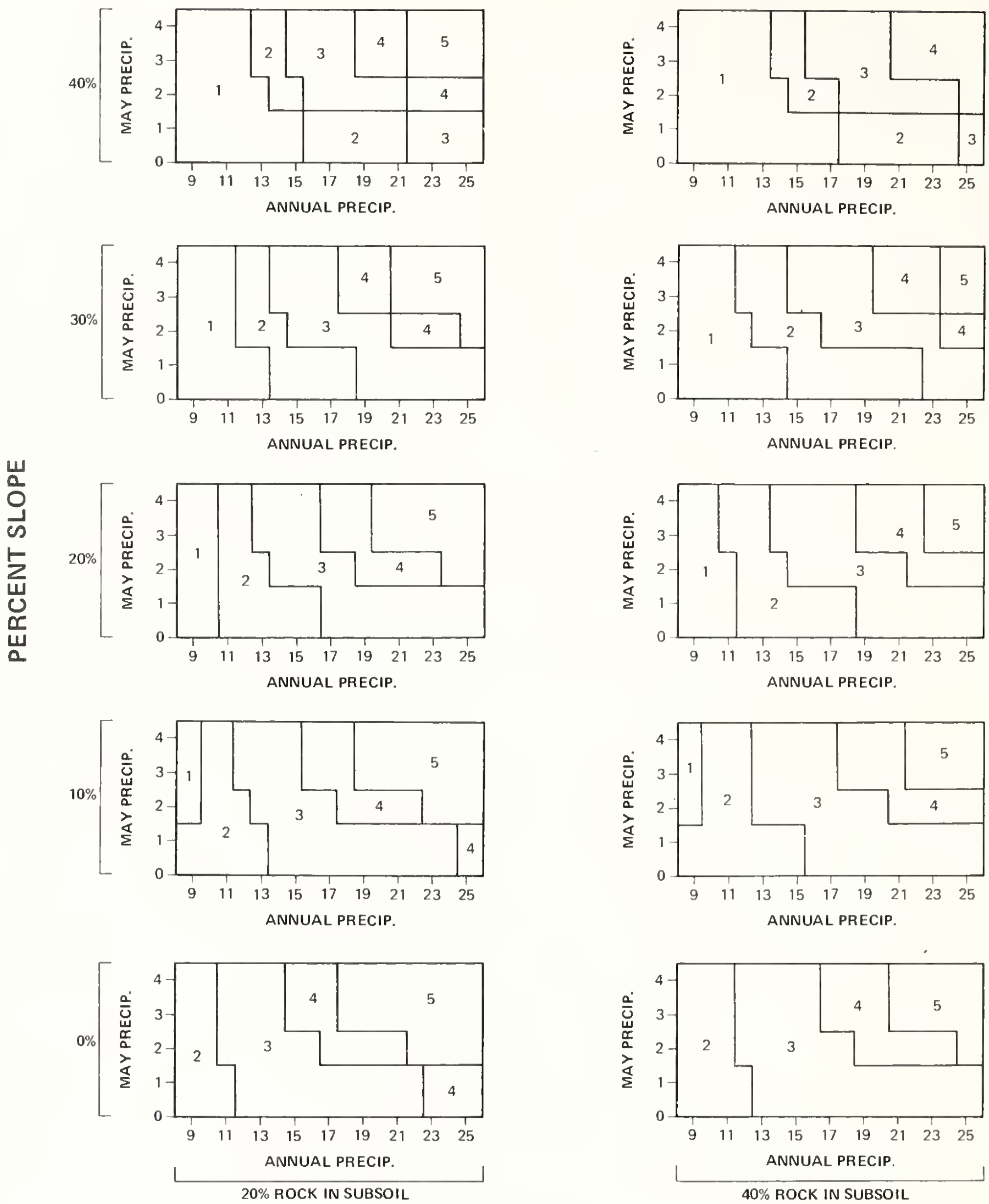
LEGEND

PRODUCTIVITY – POTENTIAL GROUPS

1. LOW
2. BELOW AVERAGE
3. AVERAGE
4. ABOVE AVERAGE
5. HIGH

Figure 9.--Chart for determining site productivity-potential group for grass mixtures according to level of annual water-year precipitation (inches), May precipitation (inches), percent rock in the subsoil (volume; coarse fragment greater than three-fourths inch), and percent slope of area.

GRASS MIXTURES II



LEGEND

PRODUCTIVITY – POTENTIAL GROUPS

1. LOW
2. BELOW AVERAGE
3. AVERAGE
4. ABOVE AVERAGE
5. HIGH

Figure 10.--Chart for determining site productivity-potential group for grass mixtures according to level of annual water-year precipitation (inches), May precipitation (inches), percent rock in the subsoil (volume; coarse fragment greater than three-fourths inch), and percent slope of area.

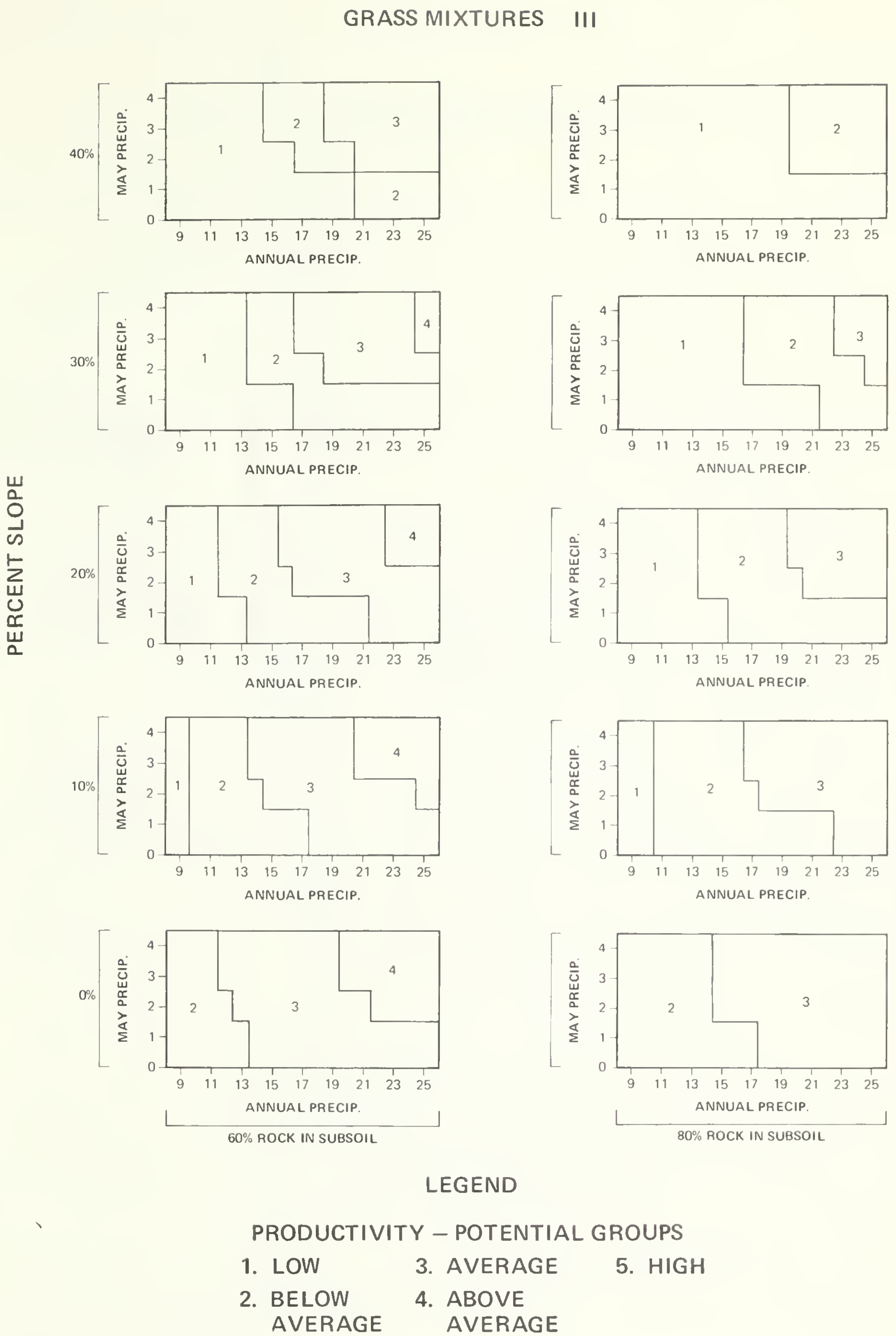


Figure 11.--Chart for determining site productivity-potential group for grass mixtures according to level of annual water-year precipitation (inches), May precipitation (inches), percent rock in the subsoil (volume; coarse fragment greater than three-fourths inch), and percent slope of area.

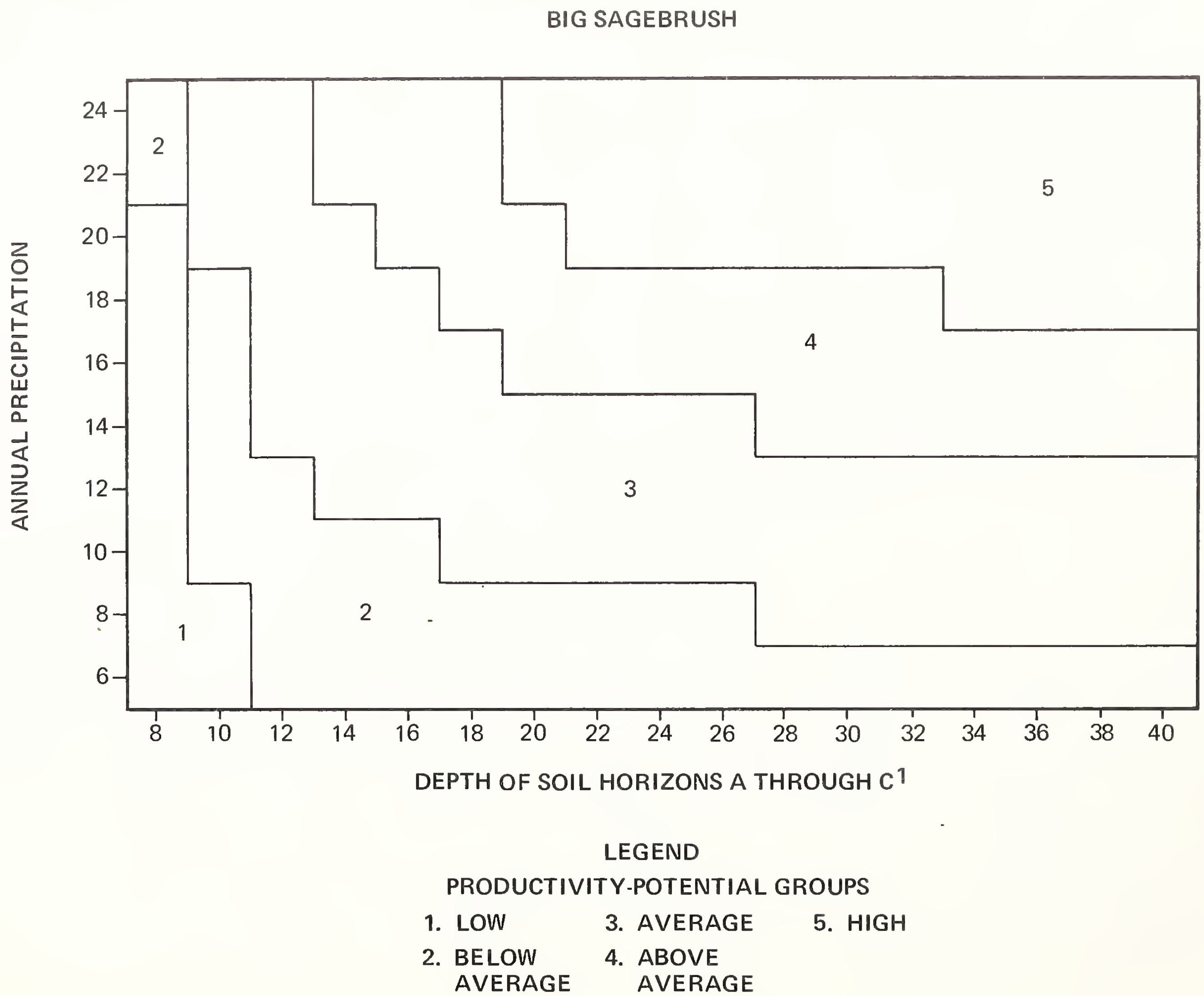
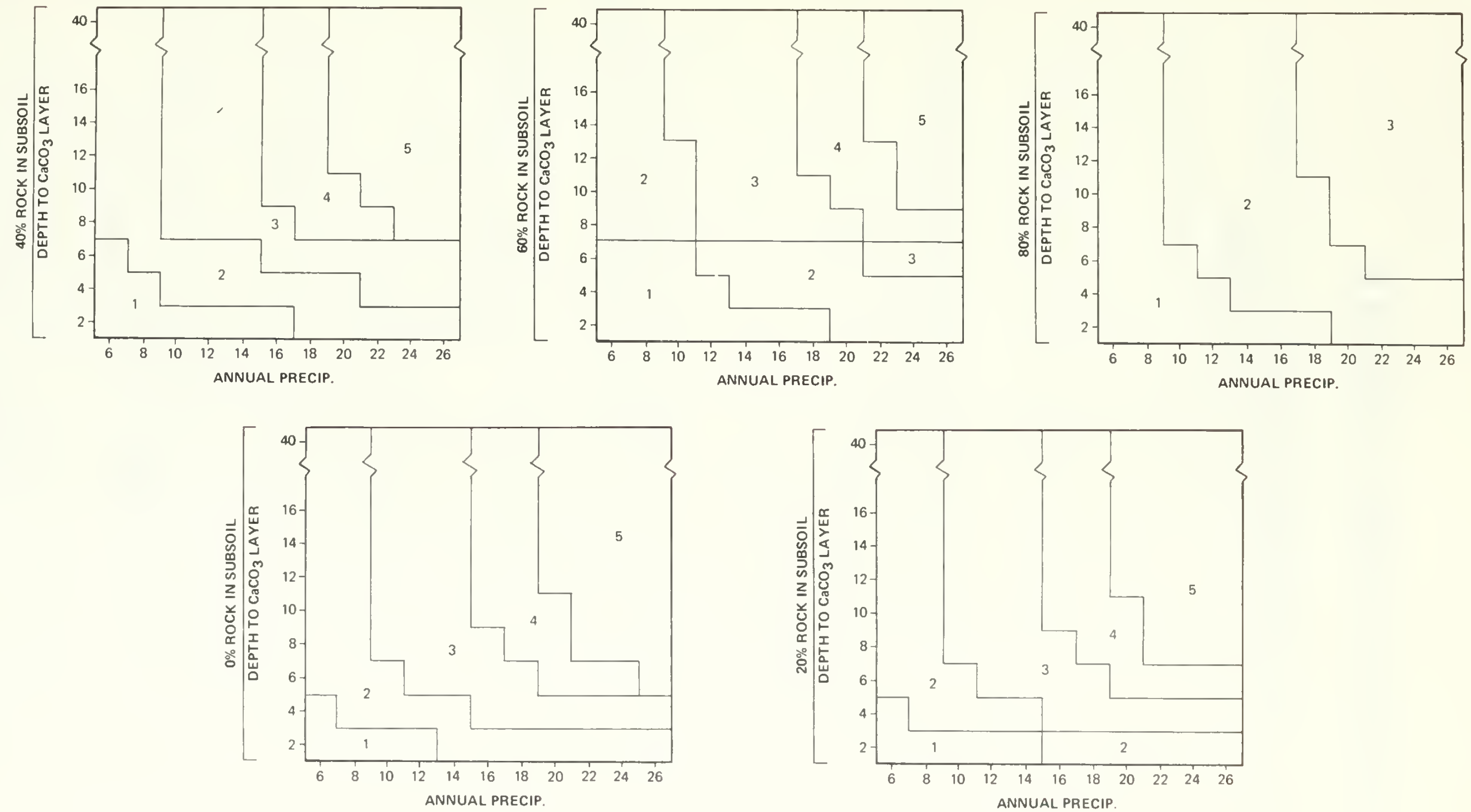


Figure 12.--Chart for determining site productivity-potential group for big sagebrush, according to level of annual water-year precipitation (inches) and depth of soil horizons A through C[1] *(inches).*

BLACK SAGEBRUSH



LEGEND

PRODUCTIVITY – POTENTIAL GROUPS

1. LOW
2. BELOW AVERAGE
3. AVERAGE
4. ABOVE AVERAGE
5. HIGH

Figure 13.--Chart for determining site productivity-potential group for black sagebrush according to level of annual precipitation (inches), percent rock in the subsoil (volume; coarse fragments greater than three-fourths inch), and depth to calcium carbonate layer (inches).

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APPENDIX I:
Derivation of Prediction Models

Interaction models were developed to represent as closely as possible the combined effects of the independent variables most strongly affecting production data for each species.

Three strongest variables for the grasses (annual precipitation, May precipitation, and percent rock in the subsoil) were included in an initial model. After the three-way interaction was accounted for, the remaining variable, percent slope, was fitted as an additive, simple linear effect.

More specifically, the data points associated with the sites were separated into all combinations of three subdivisions for the ranges of May precipitation and percent rock in the subsoil. For each of these groups, production was plotted over annual precipitation to permit examination of the three-way interaction in the light of expectation.

For the grasses, the trends were linear over annual precipitation and were fitted by approximate least deviations to the data points within each May precipitation-percent rock data group. After annual precipitation scalers were smoothed over May precipitation and percent rock data group means in accord with expectation, an algebraic descriptor was developed using curve forms and descriptor techniques from Jensen and Homeyer Matchacurves-1 and -2 (1970 and 1971) and Jensen Matchacurve-3 (1973). The resulting equation was given a final least-squares adjustment to the data points and used to provide production estimates in the production-potential charts.

The final variables adopted for big sagebrush were annual precipitation and depth of soil horizons A through C^1, while those for black sagebrush were annual precipitation, percent rock in the subsoil, and depth to calcium carbonate layer. For these two species, the modeling technique was analogous to that just described for the first three variables of the grasses.

APPENDIX II:
Equations for Models

EQUATION 1

Grasses

$$\hat{Y} = 401.4 - 39.756\,(SL) + 719.167 \left\{ L + \frac{(R-L)(AP-9)}{16} \right\}$$

where:

$$L = LR + LS\,(80-PR)$$

$$LR = 0.130 + 0.193\,e^{-\left|\frac{\frac{(4-MP)}{4} - 1}{0.593}\right|^{5}}$$

$$LS = 0.004141\,e^{-\left|\frac{\frac{(4-MP)}{4} - 1}{0.4}\right|^{10}}$$

$$R = RR + RS\,(80-PR)$$

$$RR = 1.90 + 1.30\,e^{-\left|\frac{\frac{MP}{4} - 1}{0.55}\right|^{15}}$$

$$RS = 0.0388 + 0.07725\,e^{-\left|\frac{\frac{MP}{4} - 1}{0.51}\right|^{15}}$$

Limits

$9 \text{ in} \le AP \le 25 \text{ in}$
$0 \text{ in} \le MP \le 4 \text{ in}$
$0\,\% \le PR \le 80\,\%$
$0\,\% \le SL \le 45\,\%$

Statistics

$R^2 = 0.76$
$S_{y \cdot x_i} \approx 1{,}500$ lb/acre
$\bar{y} = 1{,}908$

Where

$\hat{Y}$ = dry-weight foliage yield of fully stocked stands, pounds per acre

AP = annual precipitation, inches

MP = May precipitation, inches

PR = percent rock by volume (greater than 3/4 inch), in the subsoil

SL = slope percent

EQUATION 2

Big Sagebrush

$$\hat{Y} = P\left(1.16050\, e^{-\left|\frac{\frac{AP}{26} - 1}{0.65}\right|^{1.5}} - 0.17215\right)$$

where:

$$P = 4692\, e^{-\left|\frac{\frac{AC}{40} - 1}{0.92}\right|^{3}} - 896\, e^{-\left|\frac{\frac{(40-AC)}{32.25} - 1}{0.1}\right|^{1.5}} - 1299$$

Limits

$4 \text{ in} \leq AP \leq 25 \text{ in}$
$8 \text{ in} \leq AC \leq 40 \text{ in}$

Statistics

$R^2 = 0.56$
$S_{y \cdot x_i} \approx 900$ lb/acre
$\bar{y} = 2,045$

Where

$\hat{Y}$ = dry-weight foliage yield of fully stocked stands, pounds per acre

AP = annual precipitation, inches

AC = depth of horizons A through C[1], inches

EQUATION 3

Black Sagebrush

$$\hat{Y} = P\left(1.1160\, e^{-\left|\frac{\frac{AP}{26} - 1}{0.58}\right|^{1.5}} - 0.1160\right)$$

where:

$$P = F + (B-F)\left\{\frac{e^{-\left|\frac{\frac{(80.001-PR)}{80} - 1}{1 - I}\right|^{N}} - e^{-\left\{\frac{1}{1 - I}\right\}^{N}}}{1 - e^{-\left\{\frac{1}{1 - I}\right\}^{N}}}\right\}$$

$$F = 1532\, e^{-\left|\frac{\frac{DE}{40} - 1}{0.99}\right|^{10}} - 507$$

$$B = 2892\, e^{-\left|\frac{\frac{DE}{40} - 1}{0.92}\right|^{15}} - 88$$

$$N = 4.2\, e^{-\left|\frac{\frac{DE}{40} - 1}{0.792}\right|^{20}} + 3.8$$

$$I = 0.41\, e^{-\left|\frac{\frac{(40.001-DE)}{40} - 1}{0.18}\right|^{20}} + 0.10$$

Limits

$4 \text{ in} \le AP \le 25 \text{ in}$
$0\ \% \le PR \le 80\ \%$
$0 \text{ in} \le DE \le 50 \text{ in}$

Statistics

$R^2 = 0.65$
$S_{y \cdot x_i} \approx 500$ lb/acre
$\bar{y} = 1{,}190$

Where

$\hat{Y}$ = dry-weight foliage yield of fully stocked stands, pounds per acre

AP = annual precipitation, inches

PR = percent rock by volume (greater than 3/4 inch), in the subsoil

DE = depth to calcium carbonate layer

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STEVENS, RICHARD, A. PERRY PLUMMER, CHESTER E. JENSEN, and BRUCE C. GIUNTA
1974. Site productivity classification for selected species on winter big game ranges of Utah. USDA For. Serv. Res. Pap. INT-158, 24 p., illus. (Intermountain Forest & Range Exp. Station, Ogden, Utah 84401.)

Productivity of a mixture of four range grasses and big and black sagebrush was correlated with soil characteristics, topography, and precipitation at 21 sites considered representative of Utah's juniper-pinyon and sagebrush-grass types. The mathematical models developed provide site evaluation guides for use in range improvement programs. Charts give productivity potential in five broad groups.

OXFORD: 182.51; 268.
KEYWORDS: site productivity, juniper-pinyon, sagebrush-grass, winter big game range, big sagebrush, black sagebrush, perennial grasses.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)